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Biomass and organic waste potentials towards implementing circular bioeconomy platforms: A systematic bibliometric analysis

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ABSTRACT

Over the last decade, the increasing sustainability discourse has pushed interest in investments in the nexus of economy, bioeconomy, and the circular economy (CE). Consequently, the emerging circular bioeconomy (CBE) concept with a special focus on biomass and organic waste valorization to close product lifecycle loops has gained momentum. This research aims at providing a comprehensive map of the body of knowledge in the biomass and organic waste literature with a CBE perspective. To achieve this, a systematic bibliometric analysis is performed employing keywords, co-citation, and bibliographic coupling analyses on a total of 646 peer-reviewed articles in Web of Science. As a result, four seminal background research themes building the biomass and organic waste research in the CE were identified as follows: (1) biological conversion technologies, (2) the CE concept and its implementation, (3) environmental studies, and (4) food waste. Moreover, the results revealed that the most recent areas of research in the target literature are clustered in seven categories, including: (1) the biochar industry development from a CE perspective, (2) the role of insect biorefinery in waste management in the CE framework, (3) lifecycle assessment studies for bio-waste treatment systems, (4) the CE implementation in the agricultural sector, (5) spent coffee grounds valorization, (6) organic waste biorefinery applications in a CBE, and (7) municipal bio-waste and food waste valorization *via* anaerobic digestion. The provided map of the research on biomass and organic waste in the CBE framework can, on the one hand, support scholars in advancing the research and, on the other hand, assist practitioners and local and national authorities in implementing the CE for bio-based waste management.

1. Introduction

Renewable energy resources have become significant players in sustainable global energy strategies to reduce fossil fuels utilization worldwide [1–3]. The sustainable management of renewable resources plays a vital role in transitioning from a fossil-based and linear economy

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towards a resource-efficient, circular, and bio-based economy [4,5]. In this vein, bioenergy and biomaterial production and applications can support the sustainability of the energy-environment nexus and contribute to a cleaner and low-carbon environment [6,7]. During recent years, the increasing discourse on the necessity of creating sustainable systems for the future has pushed interest in investments in the nexus of economy, bioeconomy, and the circular economy (CE). The CE implies closing, narrowing, and slowing supply chain loops to keep materials in use as long as possible, contributing to a sustainable and zero-waste environment [8]. A bio-based CE, also known as circular bioeconomy (CBE), focuses on the resource-efficient and sustainable valorization of biomass [9].

As a carbon neutral-based renewable source of energy that comes from animal and plant materials [6], biomass has been extensively explored by scholars in the context of the CE and CBE establishment. Transitioning towards a CBE requires a comprehensive understanding of the significance of using biomass and its practical implications by stakeholders throughout the whole value chain, from product design to waste management practices [10]. The research in this area has been mainly focused on technological advancements in biomass valorization [11], biomass production for animal feed [12], conversion and application of organic waste biomass [13], energy valuation of agroforestry biomass in the CE [14], renewable energy production employing biomass-based biochar in line with CE principles [15], sustainable biomass production and its function as a feedstock in the CE [10], the contribution of agricultural waste biomass in the CE framework [16], valorization of microalgae biomass to support the CE transition [17], and waste biorefinery towards a sustainable CBE platform [6]. As a result, a huge amount of biomass-related scientific production has been evolving over recent years considering the contribution of the following factors to low-carbon development and the transition from a linear economy to a CBE: (i) biomass and organic waste streams, (ii) biomass valorization approach, and (iii) renewable technologies and biorefinery concept in production and conversion of biomass into bio-based products. Therefore, an inclusive map of the biomass waste research in the CE transition seems lacking in the literature.

To fill this gap, the present research aims to characterize and map the body of knowledge on biomass and organic waste in the CBE context. To the best of the authors' knowledge, no systematic bibliometric analysis has been performed on the biomass waste subject area towards implementing the CE and CBE in the literature. In this vein, a systematic bibliometric analysis is conducted considering keywords, co-citation links, and bibliographic coupling networks as the main units of analysis to address the following research questions (RQs):

- RQ1. How has the scientific production in biomass and organic waste research towards a CE developed over time?
- RQ2. What are the main research hotspots (keywords) within the biomass and organic waste in the CE literature?
- RQ3. What are the seminal founders (historical emergence of different perspectives) in biomass and organic waste research in the CE?
- RQ4. What are the major emergent biomass and organic waste subfields of research in the CE in the recent literature?

The remainder of this study is organized as follows. An overview of biomass to biorefineries in the emerging CBE is provided in Section 2. The overall research design, including the search strategy and target database to collect data (section 3.1), and bibliometric methods to conduct the analysis (section 3.2), are explained in Section 3. The results are presented and discussed in Section 4 in four steps, including (i) descriptive results: performance indicators (section 4.1), (ii) the keyword-based analysis: research hotspots (section 4.2), (iii) co-citation analysis (section 4.3), and (iv) bibliographic coupling analysis (section 4.4). The implications for research, outlining the potential opportunities and prospects for future developments, are proposed in Section 5. Finally, Section 6 concludes the remarks and limitations of the present research.

2. Biomass to biorefineries in the emerging CBE

Bioeconomy relies on positioning the waste biorefinery as a cornerstone for establishing the CE and a driver for combating resource scarcity, climate change, price volatility, and increasing demand challenges [18]. In this vein, sustainable biomass feedstock, as a promising alternative energy source for biofuel production in biomass-based biorefineries, plays a significant role in transitioning to a CBE.

Biorefineries, as a strategic mechanism for implementing a CBE, are infrastructure facilities for converting various biomass feedstocks to multiple bio-based products, such as biofuels, biochemicals, bioenergy, and other high-valued bio-products [19]. In this regard, the concept of biorefinery using waste has gained momentum among waste management communities over the recent years to facilitate the CE transition. For instance, food waste biorefineries to produce biofuels and bio-based materials have been under intense research due to the convergence of policies and regulations towards achieving sustainable development goals within the 2030 Agenda for Sustainable Development [20]. Table 1 provides a list of the most recent reviews on the potentials of using biomass and organic waste through the biorefinery concept to position the CE framework.

One of the main streams of the generated bio-waste worldwide is food waste [22], which can be used to recover a wide range of energy and materials due to its carbon richness [21]. This waste stream has been widely addressed by research communities seeking pathways towards supporting a CE. Food waste biorefineries for biofuels and platform chemicals production can significantly reduce adverse environmental effects and support sustainable resource management in a CBE paradigm [20]. Conducting a systematic review on food waste conversion pathways, Santagata et al. [21] outlined the opportunities for an emerging CBE as (i) reduced environmental footprint and resource efficiency, (ii) avoided loss of economic value, and (iii) conditioning stakeholders' behavior. The individual bioprocesses in the waste biorefinery approach for food waste, such as fermentation, acidogenesis, and methanogenesis, need to be optimized for generating various bio-based products and better transforming linear economy to a CBE [22]. Future technological advances in food waste management are expected to capitalize on the multi-functionality of products, boundaries, trade-offs between resources and food waste, and allocation in a circular system [23].

In this regard, although some food waste-valorizing high-end techniques have been established at a laboratory scale, appropriate implementation of these techniques at the commercial level in a sustainable way is still facing critical challenges [24]. Zabaniotou and Kamaterou [26] highlighted the lack of adequate research on spent coffee grounds biorefining approaches and the need for further realistic economic assessment of the mono-process spent coffee grounds break down at higher technology readiness level. Moreover, they showed that efficient conversion of spent coffee grounds in a cascade biorefinery depends on the cost-effective processing schemes and the spectrum of various end-products. Insect-based bioconversions, as a marketable alternative for food waste reduction, can efficiently convert several tonnes of food waste into valuable products, providing an attractive solution for closing the food value chain loop in a CBE [27].

Nevertheless, the bottlenecks of bio-waste valorization mainly lie within the technology, highlighting the importance of conducting more research on (i) improving bioenergy density to compete with commodity fossil fuels, (ii) drafting government support and policies for research and development of bio-waste valorization process, and (iii) adopting advanced technologies to generate products with competitive edge and deployment of commercial-scale facilities [25]. In this regard, the role of lifecycle assessment (LCA) methods to increase the sustainability of commercial bio-products and biofuels was outlined by Jain et al. [30].

Table 1
Recent reviews on using biomass and organic waste towards implementing a CE.

Reference	Year	Type of review	Database	Timespan	Review focus
[21]	2021	Systematic	Scopus	2014–2019	Food waste conversion pathways in the CBE
[22]	2018	Critical	Not specified	Not specified	Adopting biorefinery strategy with an integrated approach through enabling bio-processes for developing a CBE
[23]	2020	Critical	Not specified	Not specified	Sustainable food waste management potentials to achieve a CBE model
[24]	2021	Critical	Not specified	Not specified	Sustainable processing and advanced techniques extended for food waste valorization to produce bio-based products
[25]	2020	Critical	Not specified	Not specified	Upscaling feasibility of bio-waste valorization to close the loop of CBE
[20]	2021	Critical	Not specified	Not specified	Food waste biorefinery and the direction towards CBE
[26]	2019	Systematic	Scopus	2009–2018	Potentials of spent coffee grounds biorefinery in transitioning towards a CE
[27]	2020	Critical	Not specified	Not specified	Food waste valorization in insect production and processing
[28]	2021	Critical	Not specified	Not specified	Implementing biomass-based biorefineries on a large scale focusing on substrates and biotechnologies
[29]	2021	Systematic	Scopus	2009–2020	Lignocellulosic biomass-based biorefineries
[30]	2022	Critical	Not specified	Not specified	Sustainable production of bioenergy and bio-products from bio-waste in a CE

Moreover, the integration of the biomass-based biorefinery with the existing petroleum refinery was proposed by Kumar and Verma [28] as a solution to reduce the overall cost of the process. In this vein, the concept of biomass utilization in the bio-based refineries, such as lignocellulosic biomass-based biorefinery, can serve as an effective model system and archetype for successfully implementing the CBE in the future [28,29].

Although various advancements have been recorded in this area, a comprehensive knowledge map of the biomass and organic waste literature to establish a CBE through providing a systematic bibliometric review on the available scientific production is still lacking. Therefore, this research contributes to the existing studies by providing the state-of-the-art of biomass and organic waste potentials in implementing CE and CBE platforms, in particular by (i) presenting the performance indicators of scientific production in the target literature to date, (ii) mapping theoretical and practical developments within the biomass and organic waste research in the context of transitioning from a linear economy to a CE, and (iii) identifying the main areas of research, hotspots, and research tendencies in biomass and organic waste applications in the CBE framework.

3. Materials, methods, and research design

A systematic bibliometric review analysis adopted from Belussi et al. [31] and Ranjbari et al. [8,32] was performed in this study to provide the state-of-the-art of biomass and organic waste potentials and applications in implementing CE platforms. The bibliometric analysis evolved in four steps: (1) descriptive bibliographic analysis to present the publication performance in terms of time distribution, sources, authors, contributing countries and institutions, and funding agencies, (2) keyword-based analysis to identify research hotspots and tendencies, (3) co-citation analysis of the cited references to discover the major research clusters and founders of the studied discipline, and (4) bibliographic coupling analysis of the articles to map the core emergent research subfields of the target literature. Fig. 1 visualizes the overall research design and methods employed in this study, corresponding to the relevant research questions. The defined search strategy to collect the most relevant data as well as methods of analysis are described in the following sub-sections.

3.1. Search strategy and data collection

A search protocol based on the preferred reporting items for systematic reviews and *meta*-analyses (PRISMA) statement [33] was developed to systematically identify, screen, and select relevant articles from the target literature. In this vein, Web of Science (WoS) Core Collection, as the world's most trusted global citation database, was used in this research. Given the main focus of this research, different combinations of the three main keywords "biomass", "waste", and "circular economy" were tested. As a result, the following search string including AND/OR operators was constructed: ("biomass-based waste" OR "biomass waste" OR "waste biomass" OR "waste from biomass" OR "organic waste" OR "organic-based waste" OR "biowaste" OR "bio-waste" OR "bio waste" OR "bio-based waste" OR "food waste" OR "crop residue*" OR "crop waste" OR "wood residue*" OR "wood waste" OR "forest* residue*") AND ("circular economy" OR "circular bioeconomy" OR "circular bio-economy" OR "circular bio economy").

The initial run of the search string on the field "Topic: title, abstract, author keywords, and keywords plus" in WoS returned a total of 826 articles. In the next step, the results were limited to only (i) peer-reviewed articles, (ii) journal articles, and (iii) English materials. Nevertheless, no time-period limit was applied to cover all scientific production within the study area. Consequently, 766 articles published from 2011 to 2021 remained for further consideration. To ensure the quality of the studied sample to perform a reliable analysis, the remaining articles were scanned based on their titles and abstracts to exclude irrelevant articles from the analysis. As a result, 120 articles were removed, leading to a total of 646 eligible articles as the final sample for conducting the bibliometric analysis. The details of the search strategy and the article selection process are tabulated in Table 2.

3.2. Analysis methods: Clustering and data representation

Researchers have widely employed bibliometric analysis as a quantitative technique and powerful statistical tool [4] to evaluate the scientific production performance and map a body of knowledge in various fields and domains. Bibliometric approach to review the literature, with

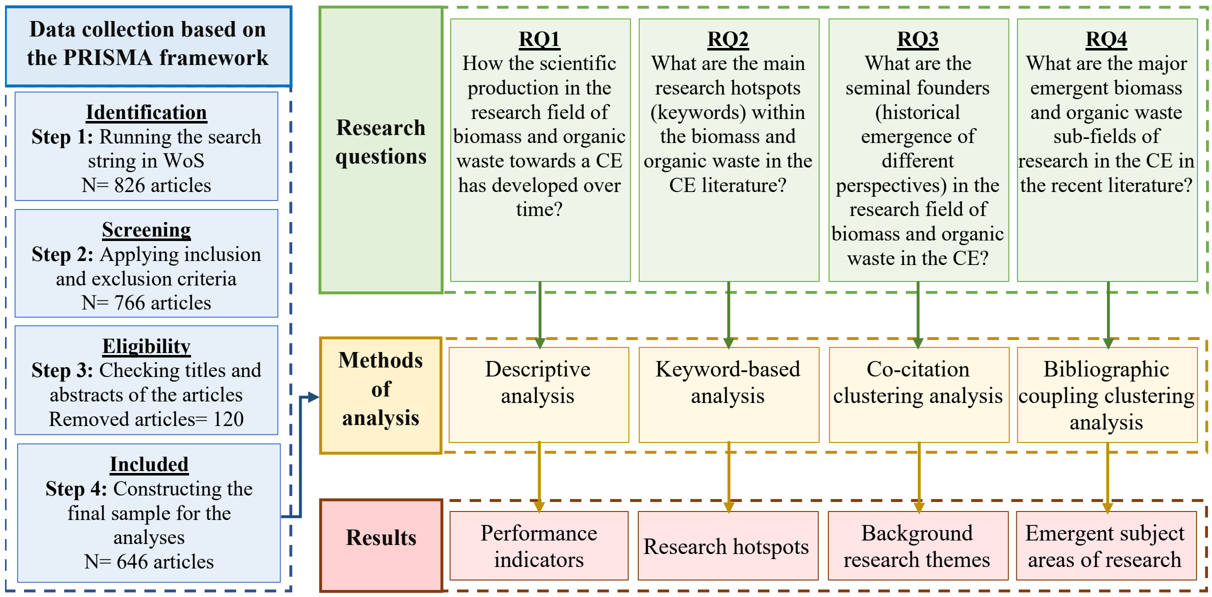


Fig. 1. The research framework.

Table 2
The search protocol to collect data from the target literature.

Search string	("biomass-based waste" OR "biomass waste" OR "waste biomass" OR "waste from biomass" OR "organic waste" OR "organic-based waste" OR "biowaste" OR "bio-waste" OR "bio waste" OR "bio-based waste" OR "food waste" OR "crop residue*" OR "crop waste" OR "wood residue*" OR "wood waste" OR "forest* residue*") AND ("circular economy" OR "circular bioeconomy" OR "circular bio-economy" OR "circular bio economy")
Searched in	Topic: title, abstract, author keywords, and keywords plus
Database	Web of Science
The last update	September 8, 2021
First Result	826 articles
Inclusion criteria	(i) English documents, and (ii) peer-reviewed journal articles
Second result	766 articles
Screening stage	120 articles were removed
Final sample	646 articles

a special focus on the links among influential articles, contributing authors, main sources, references, and citation and co-citation networks [34], supports presenting an inclusive overview of the target literature. Moreover, bibliometric techniques increase researchers' analytical ability by introducing objective measures for scientific productions assessment that contrast the potential bias embedded in subjective assessments [35].

In this research, a descriptive analysis was carried out on a total of 646 peer-reviewed articles collected from the WoS database to provide performance indicators of the scientific production in biomass and organic waste in the CBE literature. In the next step, a bibliometric analysis was conducted by following two bibliometric approaches, namely (i) the keyword-based approach and (ii) the citation-based approach. The keywords of the articles in the sample were analyzed and mapped based on their occurrence, co-occurrence, and recentness to render a general overview of the research field tendencies and hotspots. Scholars have significantly benefited from the keyword-based analysis, as a useful knowledge mapping tool for unfolding the conceptual and thematic structures of academic domains and disciplines [36]. The keywords co-occurrence analysis considers keywords as nodes, and the co-occurrence of a pair of nodes represents a link between those nodes in the constructed keywords co-occurrence network. In this context, the number of times that a pair of author keywords (nodes) co-occurs specifies the weight of the relevant link [37]. Among the citation-based approaches in bibliometric analysis, bibliographic coupling and co-citation analyses are considered the main and most accurate bibliographic techniques to assess the links between two scientific documents [31]. Therefore, co-citation and bibliographic coupling analyses were used in this research to study the possible relationship between scientific publications in the biomass and organic waste literature from the CE perspective.

The co-citation link strength between two objects (i.e., article, author, journal, etc.) refers to the number of times these two objects have been cited together by another object. On the contrary, the bibliographic coupling link strength between two objects denotes the number of times these two objects have simultaneously cited another object. On this basis, while the co-citation analysis has a backward-looking approach to the target literature, the bibliographic coupling analysis is a forward-looking perspective [31]. Therefore, in this research, co-citation analysis was employed to describe the historical evolution of the biomass and organic waste research in the CE discipline and identify its relevant major research themes. On the other hand, the articles were clustered based on the bibliographic coupling links to identify more recent research sub-fields of the subject in the literature.

The VOSviewer software version 1.6.16 [38] was used to perform the analysis. VOSviewer is a computer program developed in the Java programming language that explores and visualizes node-link maps within the documents based on bibliographic data [38,39]. Each node-link in the map denotes a bibliometric network of an object in the database, such as keywords, articles, or references, which extensively assists with better understanding and analyzing the research trends of a specific discipline [39].

4. Results and discussion

In this section, the study results are presented in four separate sections corresponding to the RQs. First, descriptive results, presenting performance indicators of the target literature, are provided in section 3.1 to answer RQ1. Second, the main findings of the keyword-based analysis are visualized and discussed in section 3.2 to address RQ2. Third, co-citation analysis to cluster the articles and identify the main research themes of the subject are presented in section 3.3

corresponding to RQ3. And finally, bibliographic coupling analysis results to map the emergent sub-fields of the research are rendered in section 3.4 to answer RQ4.

4.1. Descriptive results: Performance indicators

The provided results in this section address the first RQ:

- RQ1. How has the scientific production in biomass and organic waste research towards a CE developed over time?

4.1.1. Publications' evolution over time

To provide an insight into the evolution of publications considering biomass and organic waste from the CE lens over time, the trend of publication of articles in our considered sample dataset is plotted in Fig. 2. Among the overall 646 articles, 155 articles are review papers, constituting approximately 24% of the whole sample. Therefore, the evolution of research and review articles are also plotted separately in Fig. 2. As can be clearly seen from this figure, although biomass has a long history in research, looking at this research field from a CE point of view is a recent phenomenon, starting from 2011 based on the publication date of the oldest paper in our dataset. While from 2011 to 2015, only 5 papers in total were published, in 2016, this number tripled, as 10 new articles were published in this domain. The number of publications from 2016 onwards has experienced a drastic increase, such that only after 4 years, the annual publication reached 196 in 2020, and only by August 2021, other 254 new articles were published. The number 254 for the year 2021 captures both the articles with the publication year 2021 and also 27 early access articles in our dataset, which have no specified publishing year, yet.

The growth in the annual number of published articles in the biomass and organic waste domain from the lens of the CE is not only true about the overall number of articles, but it is also true about research and review articles, separately, the former with a much faster trend than the latter. While only 6 research articles and 4 review articles were published in 2016, these annual numbers increased to 155 and 41 in 2020, and to 162 and 62 by August 2021, respectively. The significant share of review articles from the total published articles may refer to the mass amount of research in this field that has been looked at from the CE viewpoint in research articles in recent years, resulting in the recentness of the topic.

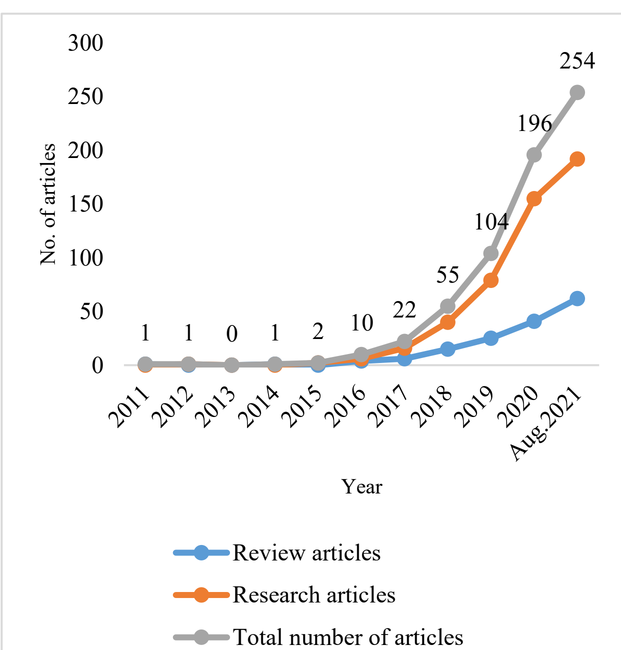


Fig. 2. The number of annual published articles in the research field of biomass and organic waste towards a CE.

4.1.2. Journals and publishers

The 646 articles in the studied dataset were published in 186 journals from 39 publishers. While Table 3 provides the list of journals with more than 10 published articles in our dataset, Fig. 3 shows the publishers' share from the published articles. Based on Table 3, Journal of Cleaner Production, Sustainability, and Bioresource Technology are the top 3 journals in terms of the number of articles, with 56, 38, and 35 articles, standing for 8.7%, 5.9%, and 5.4% of the articles, respectively. Out of the 14 journals presented in Table 3, 7 journals are published by Elsevier, making it a leader in contributing to the field. This is also confirmed by Fig. 2, as Elsevier has the largest number of published articles, followed by MDPI, with 301 and 148 articles, respectively.

4.1.3. Core articles

Considering highly cited articles as more influential in the research field [40], Table 4 and Table 5 present the 10 most influential research and review articles in our dataset, respectively. According to Table 4, the most influential research article with 93 citations in WoS was published by Sheldon [41] in Journal of Molecular Catalysis A-Chemical, highlighting waste lignocellulosic biomass valorization as a key to the sustainable production of chemicals, liquid fuels and polymers in the long term. Three out of the 10 highly cited research articles were published in Science of the Total Environment and are ranked 3rd, 7th, and 10th, earning 154 citations in total. This journal was ranked 4th in terms of the number of published articles in Table 3. The second and third highly cited research articles were published by Monlau et al. [42], referring to functional integration of anaerobic digestion and pyrolysis for sustainable resource management, and Sharma et al. [43], addressing the waste-to-energy nexus for the CE and environmental protection, receiving 78 and 63 citations, respectively.

As reported in Table 5, the highly cited review articles have received more citations than the top 10 research articles. The most cited review article with 431 citations was published by Mirabella et al. [44] on the current options for the valorization of food manufacturing waste. The review articles by Puyol et al. [45], on resource recovery from wastewater by biological technologies, and Dahiya et al. [22], on food waste biorefinery, with 197 and 188 citations, respectively, are the second and third highly cited review articles.

4.1.4. Productive and influential authors

Based on the sample of our study, a total of 2,841 authors contributed to the published articles in the domain of biomass and organic waste in the CE. Among these authors, 317 authors have at least 2 papers in this dataset. While authors with the largest number of articles in our study were considered as highly productive authors, authors with the largest number of received citations to their articles available in our dataset (WoS) were taken into account as highly influential authors. Table 6 provides the list of the most productive and also the most influential authors in biomass and organic waste research towards a CE. In this regard, Mohan S.V., with 9 published articles, is the most productive author in our dataset. The average publication year of the 9 articles authored by Mohan S.V. is 2018.89, which shows that this author has been active in this field for several years. Irabien, A. and Thomsen, M. come next, each with 8 published articles and the average publication year of 2018.38 and 2020.25, respectively, indicating that the articles published by Thomsen, M. is more recent than the ones published by Irabien, A. Within the list of highly productive authors in Table 6, Zabaniotou, A. with the average publication year of 2017.20 for 5 articles has the least recent collection of articles.

In terms of the citations received by the authors, Sala, S. is the most influential author in the biomass and organic waste applications in the

Table 3
Top productive journals with more than 10 published articles in biomass and organic waste research towards a CE.

Journal	Number of articles	Citations to articles	Publisher	Impact factor (2020)	CiteScore
Journal of Cleaner Production	56	1240	Elsevier	9.297	13.1
Sustainability	38	253	MDPI	3.251	3.9
Bioresource Technology	35	1120	Elsevier	9.642	14.8
Energies	28	148	MDPI	3.004	4.7
Science of the Total Environment	28	381	Elsevier	7.963	10.5
Waste Management	26	412	Elsevier	7.145	11.5
Renewable & Sustainable Energy Reviews	22	410	Elsevier	14.982	30.5
Waste and Biomass Valorization	17	152	Springer	3.703	4.2
Resources Conservation and Recycling	15	229	Elsevier	10.204	14.7
Journal of Environmental Management	13	107	Elsevier	6.789	9.8
Molecules	13	186	MDPI	4.411	4.7
ACS Sustainable Chemistry & Engineering	11	75	American Chemical Society	8.198	12
Applied Sciences-Basel	11	35	MDPI	2.679	3
Environmental Science and Pollution Research	11	95	Springer	4.223	5.5

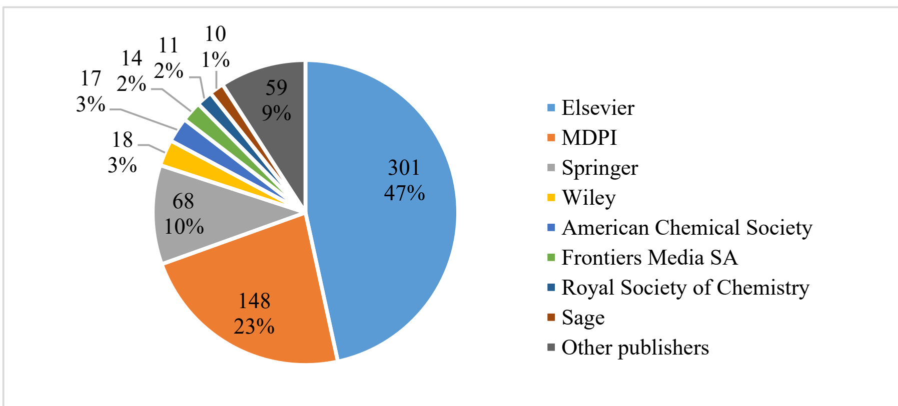


Fig. 3. Most productive publishers in the research field of biomass and organic waste towards a CE (number and percentage of articles are shown on the chart).

CE domain. This author has received 490 citations for only 2 papers with an average publication year of 2016. Castellani, V. and Mirabella, N., both with 431 citations to only 1 article published in 2014 come next. These two authors have been co-authors in a single review paper titled "Current options for the valorization of food manufacturing waste: a review" published in Journal of Cleaner Production in which Sala, S. is also a co-author [44]. The third rank for the highly influential author refers to Mohan, S.V., who is also the most productive author in our dataset.

A comparison between the average citation per article of the highly productive and highly influential authors shows that except for Mohan, S.V., the average citation per article of the most influential authors is considerably higher than that of highly productive authors. This shows the attractiveness of some papers in this research field, most of which are review articles. Besides, a comparison between the average publication year of the highly productive and highly influential authors indicates that the average publication year of the influential authors is mostly lower than that of productive authors. The lower average publication years may be another factor in earning more citations over time by the articles.

4.1.5. Author affiliations

The 2,841 authors contributing to the studied research domain were affiliated with 995 institutions worldwide. Table 7 provides the list of the most productive organizations based on the number of times their names have appeared as the authors' affiliations in our dataset. University of Padua in Italy, with 12 articles, which constitute 1.86% of the total articles in our sample, is the leading institution in this regard. The National University of Singapore in Singapore and the University of Milan in Italy, each with 11 articles, are ranked second in terms of productivity, followed by the National Technical University of Athens in Greece and Northwest A&F University in China, each with 10 articles. Among the 10 institutions listed in Table 7, three institutions are located in Italy, which shows the high productivity of the Italian institutions in research in the biomass and organic waste in the CE domain.

4.1.6. Geographical distribution: Contributing countries

A total of 83 countries contributed to the production of scientific literature on biomass and organic waste from the lens of the CE. The top 10 countries in terms of the number of published articles are presented in Table 8. As can be seen, Italy, Spain, and China, with 137, 103, and 68 articles, respectively, are the top three productive countries, publishing overall 47.59% of the articles. These countries also have the highest citation numbers compared with the other countries on the list. Considering the international collaborations among the contributing countries, Italy with 46 international partner countries and China with 121 international collaborations in their published articles are the leading countries in international co-authorship.

Table 9 provides the most frequent pairs of countries co-authoring articles in the biomass and organic waste in the CE domain based on the dataset in this research. The most frequent international collaboration has taken place between China and South Korea, referring to 12 collaborations. This collaboration is followed by the co-authorship among China and USA, China and Italy, and Italy and Spain, each with the frequency of 11. Among the 12 pairs of countries in Table 9, China has appeared in 7 pairs, England in 4 pairs, and Italy and Spain each in 3 pairs. These countries are also the top 4 countries in terms of the number of publications, according to Table 8.

Table 4
Ten most cited research articles in the research field of biomass and organic waste towards a CE.

Reference	Year	Title	Journal	Citation
[41]	2016	Green chemistry, catalysis and valorization of waste biomass	Journal of Molecular Catalysis A-Chemical	93
[42]	2016	Toward a functional integration of anaerobic digestion and pyrolysis for a sustainable resource management. Comparison between solid-digestate and its derived pyrochar as a soil amendment	Applied Energy	78
[43]	2020	Waste-to-energy nexus for circular economy and environmental protection: Recent trends in hydrogen energy	Science of the Total Environment	63
[46]	2018	Techno-economic and profitability analysis of food waste biorefineries at European level	Bioresource Technology	59
[47]	2019	Environmental sustainability of anaerobic digestion of household food waste	Journal of Environmental Management	58
[48]	2017	Farmer perceptions and use of organic waste products as fertilisers - A survey study of potential benefits and barriers	Agricultural Systems	48
[49]	2019	Environmental and economic implications of recovering resources from food waste in a circular economy	Science of the Total Environment	47
[50]	2015	Life Cycle Assessment from food to food: A case study of circular economy from cruise ships to aquaculture	Sustainable Production and Consumption	46
[51]	2016	Efficiency of a novel "Food to waste to food" system including anaerobic digestion of food waste and cultivation of vegetables on digestate in a bubble-insulated greenhouse	Waste Management	45
[52]	2020	Towards transparent valorization of food surplus, waste and loss: Clarifying definitions, food waste hierarchy, and role in the circular economy	Science of the Total Environment	44

4.1.7. *Funding agencies*

Several funding agencies have supported studies conducted in this field to encourage research in the biomass and CE domain. Among the 646 articles in this study, 502 articles have received funding support from at least one funding agency. This number of articles constitutes approximately 77.71% of the total articles considered in the present research. Table 10 provides the list of highly supporting funding agencies regarding the number of articles they have supported. Approximately 10.37% of the total articles (67 out of 646 articles) are supported by European Commission, leading this organization to be the most supportive funding agency in this research field. The next ranks refer to UK Research Innovation (UKRI) and Coordenação de Aperfeicoamento de Pessoal de Nível Superior (CAPES) with 20 and 19 articles, respectively. As can be seen from Table 10, European Commission has a significant distance from the other funding organizations in terms of the number of articles supported. The number of articles supported by the European Commission is more than three times the number of articles funded by its following organizations, showing the potential of this institution in supporting the research within the biomass and organic waste in the CE research field.

Table 5
Ten most cited review articles in the research field of biomass and organic waste towards a CE.

Reference	Year	Title	Journal	Citation
[44]	2014	Current options for the valorization of food manufacturing waste: a review	Journal of Cleaner Production	431
[45]	2017	Resource Recovery from Wastewater by Biological Technologies: Opportunities, Challenges, and Prospects	Frontiers in Microbiology	197
[22]	2018	Food waste biorefinery: Sustainable strategy for circular bioeconomy	Bioresource Technology	188
[53]	2016	Food waste valorization *via* anaerobic processes: a review	Reviews in Environmental Science and Biotechnology	113
[19]	2020	Biorefineries in circular bioeconomy: A comprehensive review	Bioresource Technology	111
[54]	2016	New Frontiers in the Catalytic Synthesis of Levulinic Acid: From Sugars to Raw and Waste Biomass as Starting Feedstock	Catalysts	106
[55]	2016	Biological processes for advancing lignocellulosic waste biorefinery by advocating circular economy	Bioresource Technology	99
[56]	2011	International comparative study of 3R and waste management policy developments	Journal of Material Cycles and Waste Management	98
[57]	2017	A roadmap towards a circular and sustainable bioeconomy through waste valorization	Current Opinion in Green and Sustainable Chemistry	93
[58]	2018	Feasibility analysis of anaerobic digestion of excess sludge enhanced by iron: A review	Renewable and Sustainable Energy Reviews	87

4.2. *Keyword-based analysis: Research hotspots*

The keyword-based analysis results in this section address the second RQ:

- RQ2. What are the main research hotspots (keywords) within the biomass and organic waste in the CE literature?

To discover the main idea and scope of the articles and identify the research hotspots within the biomass and organic waste domain in the CE, keyword co-occurrence analysis is conducted on the authors' keywords in this section. After a proper data cleaning, as an essential step in conducting keyword-based analysis [59], 1,949 keywords were identified, 332 of which had more than one occurrence. These 332 keywords were used to build the co-occurrence network of keywords in Fig. 4 and served as the base for the keywords-based analyses.

Fig. 4 presents five main categories of information regarding the author's keywords. First, it shows the keywords with at least 2

Table 6
The most productive and most influential authors in biomass and organic waste research towards a CE.

Highly productive authors						Highly influential authors					
Rank	Author	Articles	Citations	ACPA*	APY**	Rank	Author	Citations	Articles	ACPA	APY
1	Mohan, S.V.	9	288	32	2018.89	1	Sala, S.	490	2	245	2016
2	Irabien, A.	8	125	15.63	2018.38	2	Castellani, V.	431	1	431	2014
	Thomsen, M.	8	94	11.75	2020.25		Mirabella, N.	431	1	431	2014
3	Taherzadeh, M.J.	7	95	13.57	2020.57	3	Mohan, S.V.	288	9	32	2018.89
4	Awasthi, M.K.	6	95	15.83	2020.50	4	Sarkar, O.	211	3	70.33	2019
	Ok, Y.S.	6	92	15.33	2020.50	5	Hulsen, T.	206	2	103	2018.5
	Zhang, Z.	6	95	15.83	2020.50	6	Puyol, D.	205	3	68.33	2019
5	D'adamo, I.	5	129	25.80	2019.60	7	Dahiya, S.	203	3	67.67	2018.67
	Moustakas, K.	5	114	22.80	2019.40	8	Chatterjee, S.	201	2	100.50	2018
	Song, S.	5	30	6	2020.80		Sravan, J.S.	201	2	100.50	2019
	Tan, H.T.W.	5	30	6	2020.80	9	Astals, S.	197	1	197	2017
	Teigiserova, D.A.	5	83	16.60	2020.40		Batstone, D.J.	197	1	197	2017
	Tsang, D.C.W.	5	88	17.60	2020.20		Kromer, J.O.	197	1	197	2017
	Zabaniotou, A.	5	192	38.40	2017.20		Peces, M.	197	1	197	2017

* ACPA: Average citation per article.
** APY: Average publication year.

Table 7
The most productive organizations regarding the number of articles in biomass and organic waste research towards a CE.

Organizations	Country	Articles	% of total articles	citations
University of Padua	Italy	12	1.86	106
National University of Singapore	Singapore	11	1.70	53
University of Milan	Italy	11	1.70	145
National Technical University of Athens	Greece	10	1.55	169
Northwest A&F University	China	10	1.55	138
Aarhus University	Denmark	9	1.39	95
Consiglio Nazionale delle Ricerche (CNR)	Italy	9	1.39	97
University of Aveiro	Portugal	9	1.39	28
University of Cantabria	Spain	9	1.39	125
University of York	UK	9	1.39	175

occurrences in the network's nodes. Second, it reflects the frequency of appearing the keywords through the size of their corresponding nodes, such that a larger node represents a higher occurrence of the targeted keyword. Third, the co-occurrence of the keywords is shown in the network by the lines linking the nodes. Fourth, the thickness of the lines between the nodes indicates the number of co-occurrence of the pair of nodes, such that a thicker line illustrates a more frequent co-occurrence. And finally, the colors of the nodes in this figure show the recentness of the keyword, such that the darker the color of the node, the older its average publication year. The average publication year refers to the mean of the publication year of all articles that include a specific keyword among their authors' keywords.

Table 11 provides the list of the most frequent author keywords, along with their occurrence and average publication year. As can be seen in this table, the most frequent keyword is “circular economy” with 286 occurrences, followed by “food waste” with 83 occurrences. The huge difference between the occurrence of these two most frequent keywords highlights the attractiveness of the CE for researchers and their tendency to emphasize this recent approach in their analysis on the biomass and organic waste. The keywords “circular bioeconomy” and “bioeconomy” are also relatively attractive, appearing in 33 and 30 articles, respectively, and being ranked as the 9th and 11th most frequent keywords. A comparison between the average publication year of “circular economy”, “circular bioeconomy”, and “bioeconomy” shows that “circular bioeconomy” is almost a more recent attractive keyword in this domain, followed by “bioeconomy”. A glance at the other keywords in Table 11 sheds light on the various focal points (e.g., anaerobic digestion, biorefinery, biochar, etc.) in the studied domain and the concepts and

Table 9
The most collaborating pairs of countries in the research field of biomass and organic waste towards a CE.

Country 1	Country 2	No. of collaborations
China	South Korea	12
China	USA	11
China	Italy	11
Italy	Spain	11
India	China	10
Portugal	Spain	10
England	Spain	8
England	Germany	7
England	Italy	7
England	China	7
Malaysia	China	7
China	Sweden	7

Table 8
The top 10 countries in terms of the number of published articles in biomass and organic waste research towards a CE.

Rank	Country	No. of articles	% of total articles	Total citation	No. of collaborating countries	Total international collaboration	Average publication year
1	Italy	137	21.21	2231	46	103	2019.72
2	Spain	103	15.94	1002	37	84	2019.82
3	China	68	10.53	1012	32	121	2019.91
4	England	55	8.51	905	36	81	2019.47
5	India	39	6.04	638	16	44	2019.92
6	USA	37	5.73	425	36	72	2020.00
7	Poland	35	5.42	360	13	19	2019.89
8	Brazil	33	5.11	240	25	40	2020.15
9	Portugal	32	4.95	236	11	22	2020.19
10	Germany	28	4.33	395	35	65	2019.21
	Sweden	28	4.33	358	22	49	2019.68

Table 10
The most supportive funding agencies in the research field of biomass and organic waste towards a CE.

Funding Agency	Number of articles	% of total articles
European Commission	67	10.37
UK Research Innovation (UKRI)- UK	20	3.10
Coordenação de Aperfeicoamento de Pessoal de Nível Superior (CAPES)- Brazil	19	2.94
Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)- Brazil	18	2.79
National Natural Science Foundation of China (NSFC)- China	16	2.48
Portuguese Foundation for Science and Technology- Portugal	16	2.48
Engineering and Physical Sciences Research Council (EPSRC)- UK	15	2.32
Council of Scientific & Industrial Research (CSIR)- India	9	1.39
European Commission Joint Research Centre	8	1.24
Italian Ministry of Education, University and Research (MIUR)- Italy	8	1.24
Department of Biotechnology (DBT)- India	8	1.24
National Science Foundation (NSF)- USA	8	1.24

approaches to deal with the problem (e.g., LCA, resource recovery, recycling, etc.).

However, the most frequent keywords identified do not necessarily imply that all the contributing countries to this research domain have the same focal point. Instead, from the CE viewpoint, each country may focus on a different subject area within the biomass research domain. In Fig. 5, the most frequent keywords with more than 20 occurrences, excluding "circular economy", are plotted on a radar map for the identified 6 most productive countries, including Italy, Spain, China, England, India, and the USA. As can be seen from this figure, any county has its own research focus and none of these countries have paid attention to all the subject areas symmetrically or according to the ranking provided in Table 11. Even "food waste", the most frequent keyword after "circular economy", has not been considered a focal point in the research conducted by China, India, and the USA within the broad biomass and CE field of research.

The co-occurrence of the keywords shown in Fig. 4 as the links connecting a pair of nodes can deepen the insight about the approaches taken by the authors in the articles. Only 14 links in the presented keywords co-occurrence network have more than 10 occurrences. Out of

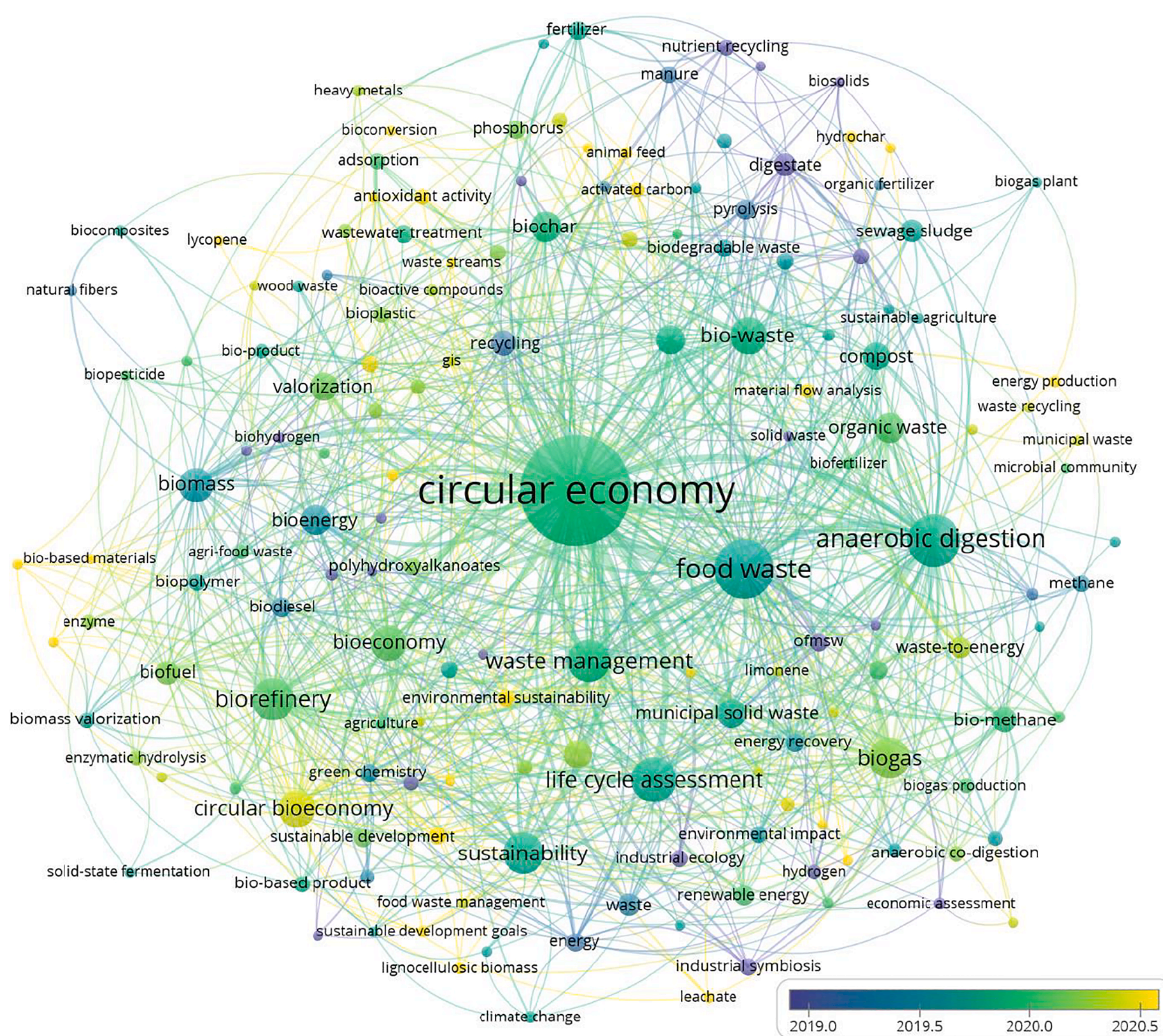


Fig. 4. Co-occurrence network of authors' keywords in the research field of biomass and organic waste towards a CE.

Table 11
The most frequent author keywords with at least 10 occurrences.

No.	Keyword	Occurrence	Average publication year	No.	Keyword	Occurrence	Average publication year
1	circular economy	286	2019.91	16	municipal solid waste	21	2019.76
2	food waste	83	2019.66	17	resource recovery	20	2019.85
3	anaerobic digestion	66	2019.79	18	compost	18	2019.78
4	LCA	48	2019.77	19	valorization	18	2020.11
5	waste management	43	2019.88	20	waste valorization	18	2020.22
6	biorefinery	42	2020.02	21	bio-methane	16	2019.94
7	biogas	41	2020.17	22	recycling	15	2019.27
8	sustainability	39	2019.77	23	biofuel	14	2020.14
9	circular bioeconomy	33	2020.36	24	digestate	13	2018.85
10	bio-waste	32	2019.88	25	sewage sludge	13	2019.69
11	bioeconomy	30	2020.07	26	waste	13	2019.39
12	biomass	29	2019.55	27	waste-to-energy	11	2020.27
13	bioenergy	23	2019.52	28	biodiesel	10	2019.40
14	organic waste	23	2020.04	29	pyrolysis	10	2019.30
15	biochar	22	2019.91	30	renewable energy	10	2020.00

these 14 links, 12 links connect “circular economy” with other keywords, including “food waste” (45 occurrences), “waste management” (25 occurrences), “LCA” (24 occurrences), “sustainability” (23 occurrences), “anaerobic digestion” (22 occurrences), “bioeconomy” (20 occurrences), “biogas” (15 occurrences), “biomass” (15 occurrences), “resource recovery” (15 occurrences), “bio-waste” (14 occurrences), “biorefinery” (14 occurrences), and “organic waste” (12 occurrences). Appearing “circular economy” in most of the pairs of keywords with the strongest links points to the highest frequency of this keyword in the sample articles. However, Table 12 presents the most frequent keyword pairs ignoring the ones that include “circular economy”.

Based on Table 12, whose information is extracted from Fig. 4, “anaerobic digestion” and “food waste” have the most co-occurrence (i.e., 19) in the keywords co-occurrence network. This pair is followed by “anaerobic digestion” and “biogas”, and “biogas” and “food waste” with 17 and 10 co-occurrences, respectively. Of the 10 pairs of keywords presented in this table, 6 pairs include “anaerobic digestion” and 4 pairs include “food waste”. Although “food waste” is a more frequent keyword in comparison with “anaerobic digestion” (83 vs. 66 occurrences), more appearance of “anaerobic digestion” in the most frequent keyword pairs indicates that the co-occurrence of “food waste” is with a higher number of keywords but with lower link strengths. This can highlight the more general view about the “food waste” in comparison with “anaerobic digestion”, and more flexibility of the “food waste” subject area to be considered from various viewpoints and in different domains from the lens of the CE.

Referring to the average publication year of the keywords shown with a color range in Fig. 4, the most recent keywords with the average publication year of 2021 refer to “energy production”, “hydrothermal carbonization”, “leachate”, “lycopene”, “supercritical fluid extraction”, “value-added product”, “wastewater”, “agro-industrial residues”, “animal nutrition”, “bio-methane production”, “biotechnology”, “cellulose”, “fish waste”, “food waste recycling”, “food waste valorization”, “greenhouse gas”, “greenhouse gas mitigation”, “hydrolysis”, “larval biomass”, “marine collagen”, “nitrogen fixation”, “nutraceuticals”, “nutrient cycling”, “pig slurry”, “polyunsaturated fatty acids”, “pomegranate”, “pyrochar”, “sustainable cities”, “sustainable energy”, “waste reuse”, and “water quality”. These keywords have an occurrence of between 2 and 4 in the whole dataset and all of them appear in the articles published in 2021. The recentness of the articles containing these keywords shows the very recent attention of the researchers towards looking at these subject areas from the lens of the CE.

On the other hand, 7 keywords have an average publication year less than 2018. The keyword “cradle-to-cradle” is the oldest one with 2 occurrences and the average publication year of 2016, followed by “levulinic acid”, “sustainable materials”, “waste composition”, “water”, and “water treatment”, each with 2 occurrences and the average publication year of 2017.5. The next old keyword is “carbon footprint” with 3 occurrences and the average publication year of 2017.67. The low average publication year of these keywords indicates weak consideration of these subject areas in more recent research and highlights the potential of considering these research topics in future research.

4.3. Co-citation analysis: Major research clusters and founders of the studied discipline

The findings of this section address the third RQ:

- RQ3. What are the seminal founders (historical emergence of different perspectives) in biomass and organic waste research in the CE literature?

The co-citation analysis was conducted on the references cited by the articles in our data sample. A total of 40,292 references had been cited by 646 articles. Due to the high number of cited references, to increase the solidity and interpretability of data clustering, a threshold of a minimum of 10 citations was applied, leading to 86 articles within the co-citation network. As a result, data clustering based on co-citation network revealed four fundamental clusters of biomass and organic waste in the CE research, including (1) biological conversion technologies with a focus on anaerobic digestion, (2) the CE concept and its implementation, barriers, and implications, (3) environmental studies, and (4) the food waste stream. These four main clusters have built the background of the research behind biomass production, utilization, and applications towards implementing the CE and CBE platforms. Fig. 6 visualizes the co-citation network and the identified major clusters. Documents within each identified cluster were sorted based on their total link strength, indicating the number of times each document appeared with another document within the list of cited references by the articles in our database. Consequently, ten articles from each cluster with the highest total link strength were selected for the analysis in this section. Table 13 presents the selected articles and their total link strength and citation.

4.3.1. Biological conversion technologies with a focus on anaerobic digestion

Waste-to-energy conversion technologies have appeared as one of the main background themes of biomass research in the context of the CE and implementing CBE platforms. In this regard, among different conversion technologies, including biological, thermal, and thermochemical, biological technologies, particularly anaerobic digestion, have played a significant role [93]. Anaerobic digestion is a process in which a consortium of microorganisms breaks down biodegradable materials into biogas in the absence of oxygen [63,94]. Interest in using anaerobic digestion to process source-segregated waste is increasing due to the opportunity of recovering additional value from waste such as

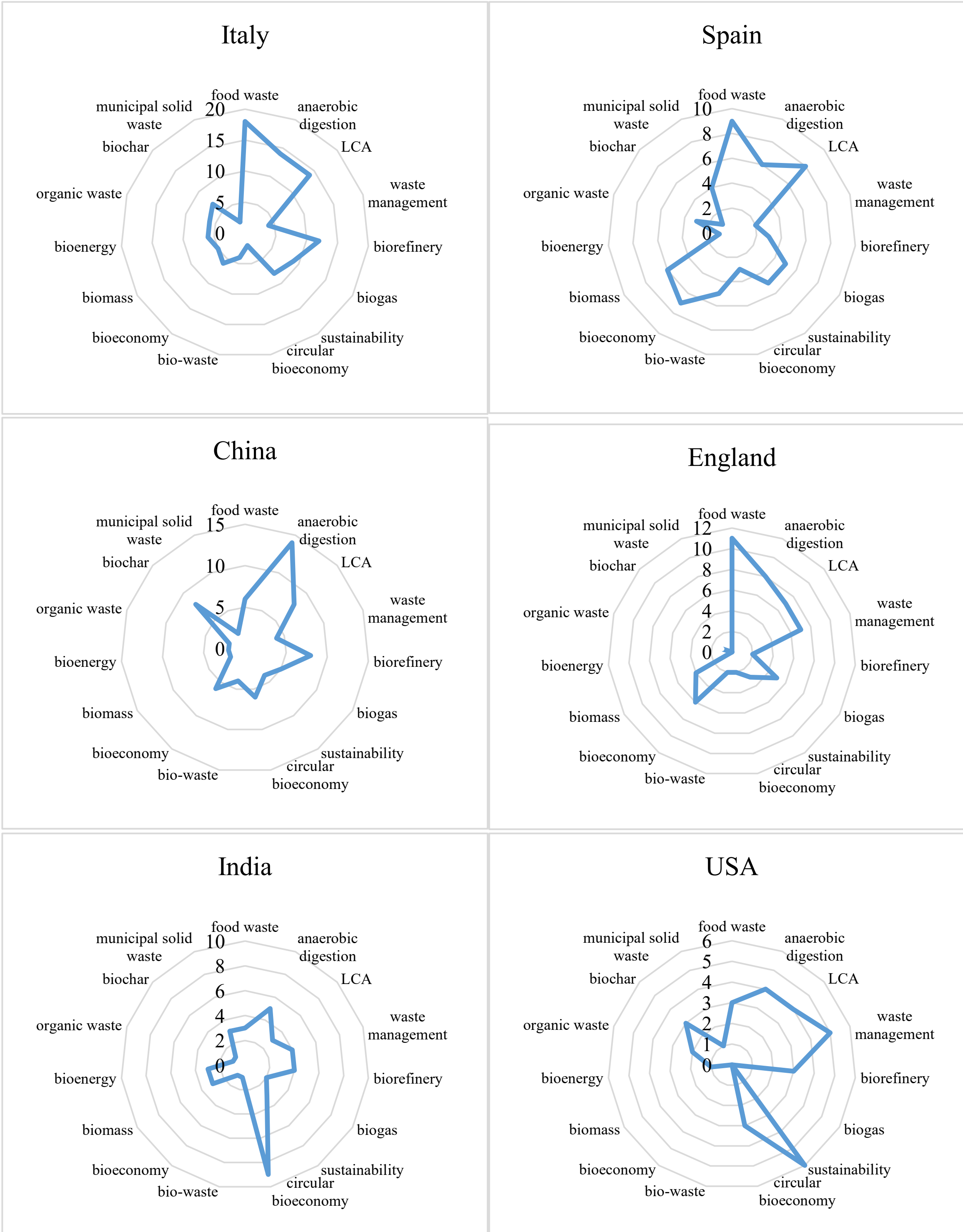


Fig. 5. Radar map of the most frequent keywords for the 6 most productive countries in biomass and organic waste research towards a CE.

nutrient-rich fertilizer products, in addition to biogas production [65,95,96]. Zhang et al. [62], in a study on the characterization of food waste as feedstock for anaerobic digestion, showed that food waste, among other organic substrates, is a highly desirable feedstock for anaerobic digestion due to its high biodegradability and methane yield.

Mismanagement of organic-based waste such as food waste has posed significant economic and environmental challenges to the global communities [97]. In this vein, with the promotion of resource recovery, more attention should be paid to biorefinery technologies for producing energy from organic waste and biomass toward a zero-emission economy and production [64]. According to Uçkun Kiran et al. [98], food waste to energy bioconversion to generate ethanol, methane, hydrogen, and biodiesel seems to be economically viable. To properly manage food waste, anaerobic digestion is a promising conversion technology compared with traditional disposal methods, such as landfilling, composting, and incineration [60,61]. However, anaerobic digestion has not been widely used to recover energy from food waste due to economic and technical challenges, such as economic viability and high cost,

Table 12
Most frequent pair of keywords ignoring the pairs involving "circular economy".

Keyword 1	Keywords 2	Link strength
anaerobic digestion	food waste	19
anaerobic digestion	Biogas	17
biogas	food waste	10
biorefinery	circular bioeconomy	10
food waste	LCA	8
food waste	Sustainability	8
anaerobic digestion	bio-methane	7
anaerobic digestion	bio-waste	7
anaerobic digestion	LCA	7
anaerobic digestion	organic waste	7

control process instability, foaming control, and low buffer capacity [60]. To enhance the waste treatment efficiency in anaerobic digestion, the adaptation of microorganisms tolerant to inhibitory substances, co-digestion with different types of biomass, and methods incorporating to counteract or remove toxicants before anaerobic digestion were proposed by Chen et al. [66] and Tabatabaei et al. [96]. In addition, Capson-Tojo et al. [53] suggested trace elements addition and solid digestate recirculation to effectively stabilize the anaerobic digestion process. Moreover, the efficient direct use of digestate generated during converting organic waste into biogas through anaerobic digestion as a substrate and stand-alone fertilizer for processing organic waste into new food was proposed by Stoknes et al. [51].

4.3.2. *The CE concept and its implementation, barriers, and implications*

Transitioning from a traditional linear economy with a take-make-dispose business model towards a CE with closed loops of materials has gained momentum among scholars and research communities in the last decade. This is proved by the booming publications on the CE subject in scientific databases. For instance, 3,152 articles including "CE" in their title have been published in WoS up to September 2021, while this number was 194 articles by 2010. The CE, as an economic system, intends to replace the "end-of-life" concept with 4Rs strategies, including reducing, reusing, recycling, and recovering within production and consumption patterns [71]. In this context, the main focus is on the closing-the-loop production processes to (i) increase resource efficiency, (ii) minimize the generated amount of waste, in particular urban and industrial streams, and (iii) achieve better harmony and balance

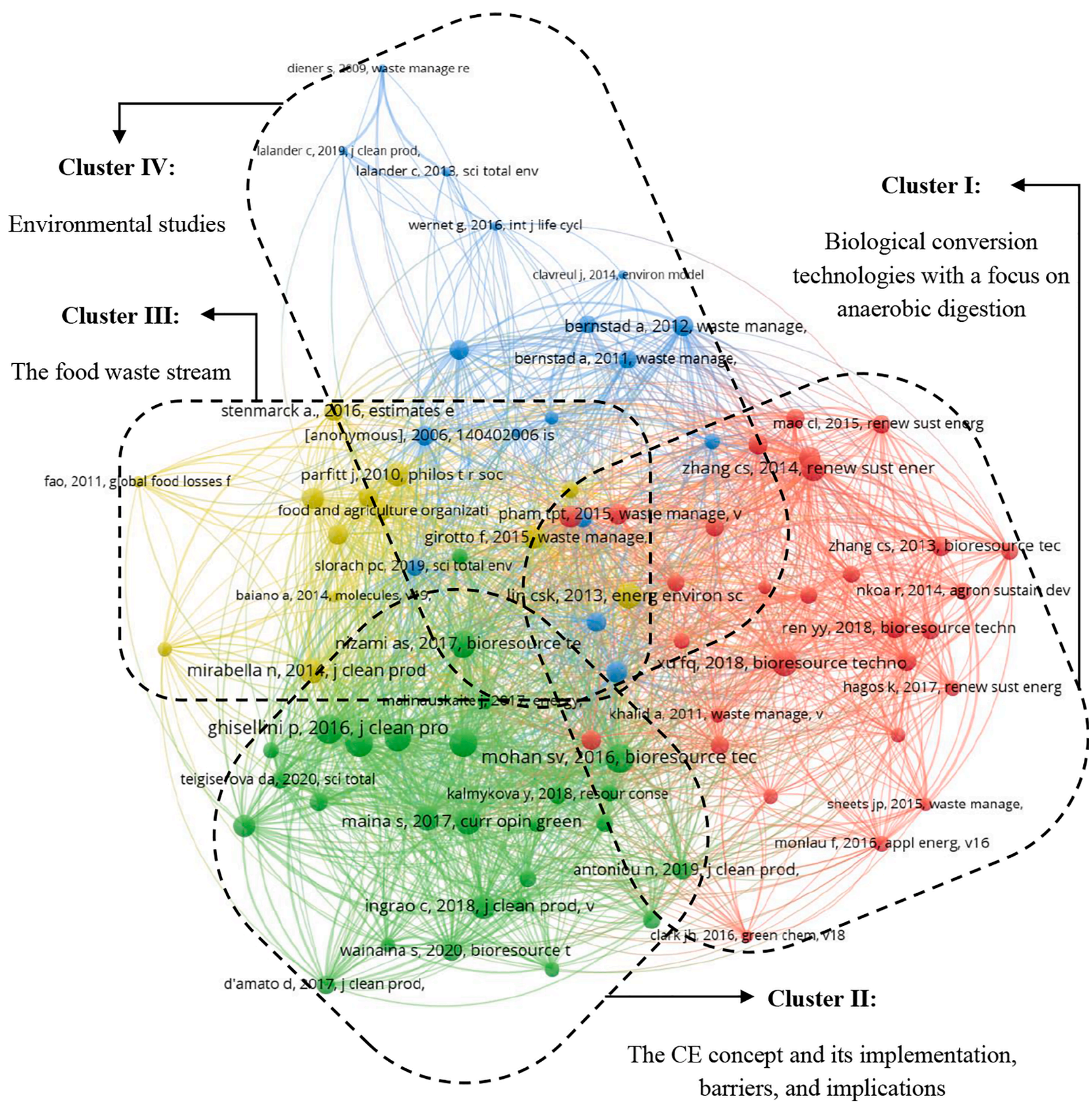


Fig. 6. Co-citation clustering: Major research clusters and founders of biomass and organic waste research in the CE context (background research themes).

Table 13
The top ten documents within each background research cluster in terms of the total link strength.

Author(s) and year	Title	Total link strength	Citation	Year	Reference
Cluster I: Biological conversion technologies with a focus on anaerobic digestion					
	Anaerobic digestion of food waste - Challenges and opportunities	128	23	2018	[60]
	Reviewing the anaerobic digestion of food waste for biogas production	115	18	2014	[61]
	Food waste valorization *via* anaerobic processes: a review	94	13	2016	[53]
	Characterization of food waste as feedstock for anaerobic digestion	93	14	2007	[62]
	Food waste-to-energy conversion technologies: Current status and future directions	89	14	2015	[63]
	A comprehensive review on food waste anaerobic digestion: Research updates and tendencies	83	14	2018	[64]
	Anaerobic digestion of source-segregated domestic food waste: Performance assessment by mass and energy balance	81	17	2011	[65]
	Efficiency of a novel "Food to waste to food" system including anaerobic digestion of food waste and cultivation of vegetables on digestate in a bubble-insulated greenhouse	76	12	2016	[51]
	Inhibition of anaerobic digestion process: A review	76	20	2008	[66]
	The anaerobic co-digestion of food waste and cattle manure	73	12	2013	[67]
Cluster II: The CE concept and its implementation, barriers, and implications					
	Waste biorefinery models towards sustainable circular bioeconomy: Critical review and future perspectives	176	38	2016	[68]
	A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems	175	30	2016	[69]
	Food waste biorefinery: Sustainable strategy for circular bioeconomy	162	32	2018	[22]
	The Circular Economy A new sustainability paradigm?	160	34	2017	[70]
	Conceptualizing the circular economy: An analysis of 114 definitions	148	24	2017	[71]
	Waste biorefineries: Enabling circular economies in developing countries	141	26	2017	[72]
	A roadmap towards a circular and sustainable bioeconomy through waste valorization	137	20	2017	[57]
	Food waste recovery into energy in a circular economy perspective: A comprehensive review of aspects related to plant operation and environmental assessment	122	18	2018	[73]
	Circular Economy: The Concept and its Limitations	116	23	2018	[74]
	Transition towards Circular Economy in the Food System	93	14	2016	[75]
Cluster III: The food waste stream					
	Food waste as a valuable resource for the production of chemicals, materials and fuels. Current situation and global perspective	130	30	2013	[76]
	Current options for the valorization of food manufacturing waste: a review	121	22	2014	[44]
	Food waste within food supply chains: quantification and potential for change to 2050	106	22	2010	[77]
	Food waste generation and industrial uses: A review	105	23	2015	[78]
	The food waste hierarchy as a framework for the management of food surplus and food waste	96	12	2014	[79]
	Carbon footprint of food waste management options in the waste hierarchy - a Swedish Case study	79	10	2015	[80]
	Food wastage footprint, Impacts on natural resources	76	15	2013	[81]
	Estimates of European food waste levels	73	15	2016	[82]
	Global food losses and food waste – Extent, causes and prevention	65	14	2011	[83]
	Recovery of high added-value components from food wastes: Conventional, emerging technologies and commercialized applications	44	11	2012	[84]
Cluster IV: Environmental studies					
	Review of comparative LCAs of food waste management systems - Current status and potential improvements	92	13	2012	[85]
	Environmental sustainability of anaerobic digestion of household food waste	88	14	2019	[47]
	Environmental Management—Life Cycle Assessment—Principles and Framework (ISO 14040:2006)	81	19	2006	[86]
	An environmental analysis of options for utilising wasted food and food residue	80	10	2016	[87]
		79	19	1997	[88]

(*continued on next page*)

Table 13 (*continued*)

Author(s) and year	Title	Total link strength	Citation	Year	Reference
	Environmental Management—Life Cycle Assessment—Principles and Framework (ISO 14040:1997)				
	A life cycle approach to the management of household food waste - A Swedish full-scale case study	67	13	2011	[89]
	Life cycle assessment of energy from waste *via* anaerobic digestion: A UK case study	61	10	2014	[90]
	Environmental and economic implications of recovering resources from food waste in a circular economy	60	13	2019	[49]
	Composting of food wastes: Status and challenges	56	16	2018	[91]
	Life Cycle Assessment of management systems for sewage sludge and food waste: centralized and decentralized approaches	49	10	2013	[92]

among society, economy, and the environment [69]. Hence, the CE contributes to (i) high-quality material cycles and high value and (ii) incorporating the possibilities of sustainable production and sharing economy to promote a more sustainable production-consumption culture [74].

However, the CE and sustainability concepts seem interconnected with similarities and differences. In this vein, Geissdoerfer et al. [70] highlighted their main differences as (i) sustainability aims at benefiting society, economy, and the environment at large, while the CE mainly benefits the economic actors that implement the system, and (ii) sustainability performs based on shared responsibility, while governments, policy-makers, regulators, and private businesses are mainly responsible for transitioning from a linear to a CE. Due to the increasing attention worldwide to the CE implementation in a wide range of disciplines and domains, a huge amount of research has been done in different industries and businesses. Overall, the CE research background has mainly focused on defining and conceptualizing the concept [54,58,77], implementing strategies, and enabling the transition towards a CE in general [57,68,73,75] and with a focus on developing countries [72]

4.3.3. The food waste stream

Food waste representing a massive market inefficiency has posed a severe challenge to the global economy, food supply chains, and agricultural and industrial systems. Approximately 1.3 billion tons/year, representing one-third of all food produced, is never eaten and is lost or wasted globally [99], which calls all waste management sectors from collection to disposal to explore sustainable solutions [78]. Households and processing are the most contributing sectors to food waste generation, accounting for more than 70 percent of the European Union's food waste [82]. Moreover, the carbon footprint of food loss and waste is estimated to be 3.3 Gtonnes of CO_2, which makes food wastage rank as the third top emitter after the USA and China in the world [81]. The first step towards a more sustainable resolution to properly manage food surplus and food waste is adopting a sustainable production and consumption culture [79]. The food waste generation covers all the food lifecycle from agriculture at the beginning to industrial manufacturing and processing, retail, and household consumption [44]. Although such an enormous amount of waste has raised serious waste management issues, it has brought some potentials and opportunities to be treated, valorized, and reused in other production systems through biorefinery platforms [44,100,101]. In this regard, food waste, as a valuable resource with a high possibility to be used as a raw material for the production of chemicals, materials and fuels [76], need to be paid attention to more intensively by waste-management authorities. Galanakis [84] highlighted food waste as a cheap source, since the conversion technologies allow the recovery of high added-value components from food waste inside food chains as functional additives in a wide range of products.

4.3.4. Environmental studies

This cluster highlights the role of environmental concerns in the wake of improper waste management, increasing the amount of waste generated worldwide and using fossil fuels to direct research towards establishing a CBE. The main focus of research in this area has been on assessing the potential environmental impacts of various treatment methods for bio-based waste streams. In this regard, LCA methods and tools based on the ISO14040-44:2006 standard [86] have been widely applied. However, the outcomes of LCA methods can vary due to differences in system boundary setting, methodological options (for instance, evaluating global warming potentials to biogenic carbon emissions), and input data variations [85,102]. Righi et al. [92] showed that the anaerobic co-digestion of organic fraction of municipal solid waste and dewatered sewage sludge with composting post-treatment in small plants might propose an environmentally sustainable choice for waste management in small communities. In another study, Slorach et al. [49] denoted that anaerobic digestion has the lowest environmental impacts per tonne of waste treated. According to their research, among incineration, in-vessel composting, anaerobic digestion, and landfilling, in-vessel composting was the least environmentally sustainable option.

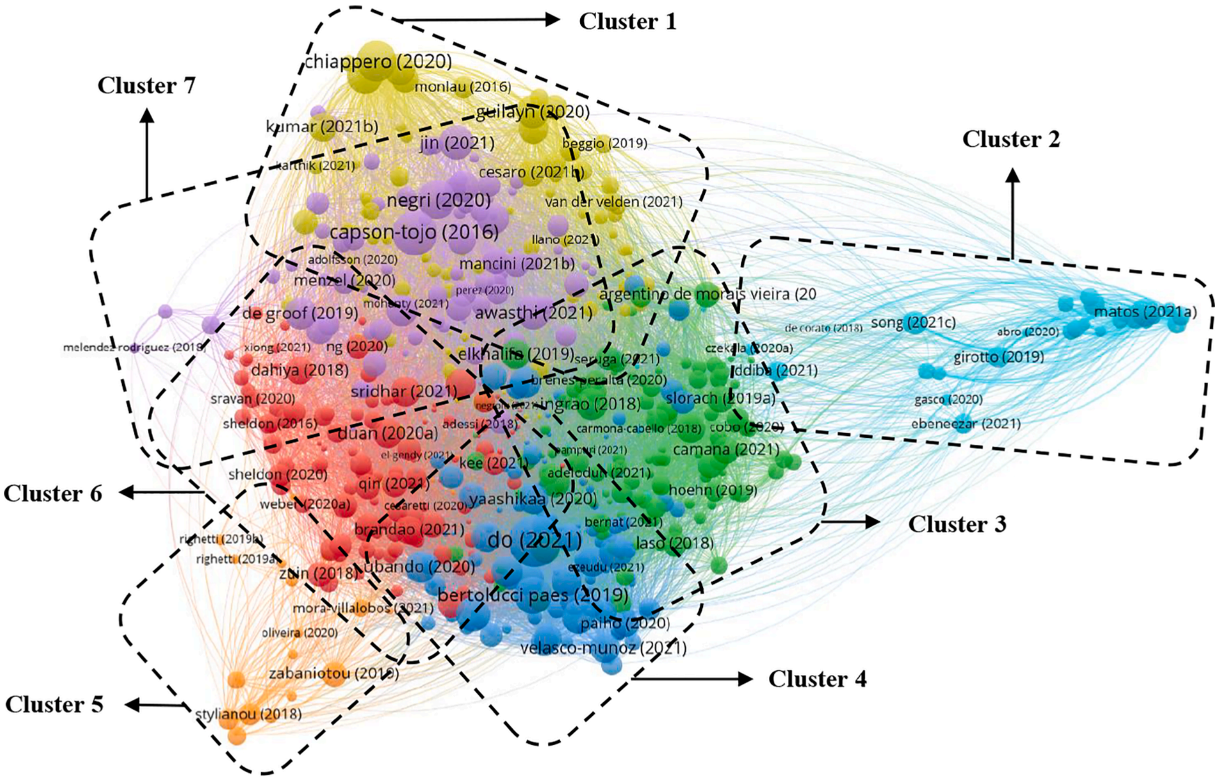
Moreover, in a comparative full-scale case study, Bernstad and la Cour Jansen [72] showed that both anaerobic and aerobic treatment methods result in net avoidance of greenhouse gas emissions. Still, compared with incineration, they contribute more to nutrient enrichment and acidification. Evangelisti et al. [90], in a study based on life-cycle inventory data of the Greater London area, outlined that when energy and organic fertilizer substitute non-renewable electricity and inorganic fertilizer, anaerobic digestion is the best treatment option considering total CO_2 and total SO_2 saved. They introduced incineration as the most environmentally friendly option for photochemical ozone and nutrient enrichment potentials. For wasted food and food residue utilization in the CBE, among four waste management options, including minimization, anaerobic digestion, composting, and incineration, the lowest environmental impact and the best carbon return on investment was obtained by anaerobic digestion [87]. Nevertheless, although anaerobic digestion has lower environmental impacts, it may lead to higher marine eutrophication, terrestrial acidification, and particulate matter formation compared with incineration and landfilling due to the application of digestate to land and the release of ammonia and nitrates [47].

4.4. Bibliographic coupling analysis: Discovering emergent research areas

The results obtained from bibliographic coupling analysis in this section address the fourth RQ:

- RQ4. What are the major emergent biomass and organic waste subfields of research in the CE in the recent literature?

To provide a map of the emergent research themes, the bibliographic coupling analysis was conducted on the articles in our sample. In this regard, articles were clustered based on the number of references they shared. Among the 646 total articles in our sample, 11 articles shared no references with other articles, and therefore, they were removed from the clustering process. As a result, the remaining 635 articles formed seven clusters, as illustrated in Fig. 7 and reported in Table 14. These



Cluster 1: The biochar industry development in a CE perspective
Cluster 2: The role of insect biorefinery in waste management in the CE framework
Cluster 3: LCA studies for bio-waste treatment systems
Cluster 4: The CE implementation in the agricultural sector
Cluster 5: Spent coffee grounds valorization
Cluster 6: organic waste biorefinery applications in a CBE
Cluster 7: Municipal bio-waste and food waste valorization *via* anaerobic digestion process

Fig. 7. Bibliographic coupling clustering: Emergent research areas in biomass and organic waste research towards the CE (the most recent themes).

Table 14
Bibliographic coupling clusters details.

Cluster name	Number of articles	Average publication year	Oldest article publication year	Sample articles
Cluster 1: The biochar industry development from a CE perspective	109	2019.87	2012	[103–109]
Cluster 2: The role of insect biorefinery in waste management in the CE framework	37	2020.05	2017	[110–116]
Cluster 3: LCA studies for bio-waste treatment systems	128	2019.85	2015	[47,117–123]
Cluster 4: The CE implementation in the agricultural sector	116	2019.86	2017	[124–129]
Cluster 5: Spent coffee grounds valorization	22	2020.13	2018	[26,130–135]
Cluster 6: organic waste biorefinery applications in a CBE	133	2019.85	2014	[20,22,46,57,136–142]
Cluster 7: Municipal bio-waste and food waste valorization *via* anaerobic digestion process	90	2019.84	2016	[53,143–147]

seven clusters represent the major emergent sub-fields of research in biomass and organic waste research towards transitioning to a CBE, including (1) the biochar industry development from a CE perspective, (2) the role of insect biorefinery in waste management in the CE framework, (3) LCA studies for bio-waste treatment systems, (4) the CE implementation in the agricultural sector, (5) spent coffee grounds valorization, (6) organic waste biorefinery applications in a CBE, and (7) municipal bio-waste and food waste valorization *via* anaerobic digestion. The aforementioned research areas are the most recent subjects in the target literature, with the total average publication year of 2019.87, as shown in Table 14.

4.4.1. *The biochar industry development from a CE perspective*

The main focus of this cluster is on biochar as a biomass-derived material and its applications to enable CE platforms. This cluster includes 109 articles with an average publication year of 2019.87, representing a hot research topic in this area. Biochar is a carbonaceous material produced *via* biomass waste thermochemical conversion [107,148,149] and can be used as a cost-effective and environmentally friendly solution to remove a wide range of organic and non-organic pollutants [150]. As a by-product produced during gasification or pyrolysis of waste biomass in biorefineries, biochar has a great potential to support transitioning towards the CE, reduce the environmental impacts, and mitigate the climate change crisis [106]. The research in this cluster has been mainly focused on investigating biochar utilization in the anaerobic digestion of food waste and loss in line with CE principles *via* digestate treatment and biogas upgrading [104], biochar role as an additive in anaerobic digestion processes [108], coupling biochar with anaerobic digestion in a CE perspective to promote sustainable energy and agriculture development [103], and biochar integration with anaerobic fermentation as a win–win strategy in a closed-loop approach [109]. Besides serving as a stability enhancer, CO_2 adsorbent for biogas, and improvement agent for digestate quality in anaerobic digestion, biochar can be used as a soil conditioner and bio-adsorbent [151]. Nevertheless, despite the promising potential uses of biochar as activated carbon, construction material, and agriculture and horticulture sectors, the research on its benefits remains significantly arguable [106].

4.4.2. *The role of insect biorefinery in waste management in the CE framework*

This subject area highlights the contribution of insects to waste management according to the CE objectives regarding valorizing waste as much as possible. Research in this cluster is recent and limited, as the first article published goes to 2017, and compared to the other clusters, this cluster has the second-fewest articles (N = 37). Besides, the average publication year is 2020.05, denoting the recentness of the research. The global increasing protein consumption to feed humans and animals has drawn significant attention to insect rearing [115]. Insect biorefineries produce biofuel and protein and transform organic waste into insect biomass [152]. In this vein, insects are mainly used as a feed source for monogastric animals, supporting the sustainability of meat/fish production systems and reducing environmental effects [115]. Moreover, using animals in waste processing to recover materials and renewable energies, such as biofuels, indicates a suitable fit with the regenerative nature of CE systems [114]. For instance, Jagtap et al. [113], in a research contributing to the design of a food system based on a CE model, identified black soldier fly larvae as a bioreactor that converts food waste into high-value feed materials. The core research in this cluster have highlighted the potential of bioconversion of animal manure using fly Larvae to promote a CE in agricultural systems [112], the *Hermetia illucens* insect applications in food waste management [111], and organic wastes upcycling for biodiesel production from *Hermetia illucens* based on a CE framework [110]. Insect biorefineries are economically feasible at both small and large scales [153]. However, the concept of insect biorefinery to address the CE essentials still needs to be better elucidated regarding safety practices and regulations when making a chain including waste, insects, and feed/food [114].

4.4.3. *LCA studies for bio-waste treatment systems*

This cluster stands as the second-largest cluster of our bibliographic coupling analysis in terms of the number of articles (N = 128). Although LCA methods and tools have been employed in environmental studies for a long time, their usage in bio-waste treatment systems has appeared as an emergent research area with an average publication year of 2019.85. From a circular bioeconomy viewpoint, applying the LCA method that considers a cradle-to-grave system boundary to have a sound design of a biorefinery is crucial [19]. In the CE transition, waste management as a central activity with a high potential of environmental impacts must be assessed from the environmental performance point of view [119]. On this basis, LCA methods have been widely used for environmental evaluation of waste management practices and waste treatment scenarios, such as residual bio-waste management strategies [117], biological treatments of bio-waste from the lifecycle perspective [118], comparison of different organic fractions of municipal solid waste collection systems [120], lifecycle environmental sustainability of recovering energy and fertilizers from household food waste [47], and food waste-to-food strategies corresponding to the CE model [122]. Sridhar et al. [136] believe that LCA and bioeconomy models show promising approaches to support effective decision-making. However, since the boundary selection significantly affects LCA outcomes [154], different waste systems should be properly integrated to avoid temporal or spatial shifts of environmental impacts [123].

4.4.4. *The CE implementation in the agricultural sector*

The agricultural sector, as one of the most potential sectors in contributing to the CE transition, has been investigated by sustainability and CE researchers and practitioners. Agricultural residues or lignocellulosic biomass constitute a part of the second generation of biofuels [155]. A total of 116 articles belong to this cluster, as one of the seven identified emergent subject areas of research, with an average publication year of 2019.86. The CE supports a sustainable and regenerative agriculture system, mainly through proposing suitable strategies for agricultural waste valorization. In this regard, integrated valorization of fruit by-products to achieve CE objectives [125], developing a CE framework for sustainable agri-food supply chains [128], and bioenergy production [124] are some recent subjects of study. Nevertheless, although a huge amount of research has been conducted on implementing the CE in the agriculture sector, theoretical CE models and frameworks have not yet been adopted in the agriculture field [126].

4.4.5. *Spent coffee grounds valorization*

The fewest number of articles belongs to this cluster (N = 22). The research in this area based on our sample data is very recent, with the first paper published in 2018 and the average publication year of 2020.13. Coffee is the second most traded commodity after petroleum [156], highlighting the key role of coffee industries in the global economy due to job creation and income reporting [26]. Consequently, the global coffee industry generates a huge amount of bio-waste and by-products, such as coffee spent grounds, and coffee silverskin that are incinerated, composted, or mainly thrown away for landfilling without recycling for other purposes[157]. As a result, sustainable management of the coffee industry and its associated by-products/wastes and value addition seems crucial in transitioning towards a CBE. The continuously increasing coffee consumption has generated massive quantities of solid residues in return in the form of spent coffee grounds, which is considered as a low-cost and promising feedstock with huge valorization potentials for the production of bio-syngas, compost, electricity, green composites, and biodiesel through biorefineries [135]. The focus of studies in this cluster has been principally on the valorization of spent coffee grounds for biodiesel production [133], utilization of spent coffee grounds in packaging development in the CE context [132], the potential of spent coffee grounds as a second-generation feedstuff and an alternative ingredient in dairy cattle [131], and converting environmental risks to benefits [130]. Although mono-process extraction methods of spent coffee grounds have been widely studied, biorefining approaches are still at an early research stage [26]. In this regard, implementing a biorefinery to valorize spent coffee grounds highly depends on the characteristics of the residues and economic interest and availability of the obtained products [134].

4.4.6. *Organic waste biorefinery applications in a CBE*

The highest number of articles (N = 133) have appeared in this cluster, with the average publication year of 2019.85, highlighting the applications of biorefinery systems for organic waste from a CBE perspective. Due to the global attention to shift towards sustainable development, food waste biorefineries have recently gained momentum because of their capabilities in producing biofuels and bio-based materials from food waste valorization [20]. Hence, many research activities have been carried out to study the characteristics, applications, and implications of food waste biorefineries for implementing a CBE. The food waste biorefinery approach should be optimized regarding the cascade of individual bioprocesses for transitioning from a linear economy to a CBE [22]. In this regard, the major topics of research have been resource recovery and biorefinery potentials of organic waste in the CBE [141], refining biomass residues for sustainable energy and bio-products [140], conversion of food waste to energy with a focus on LCA and sustainability [136], high-value food waste and food residues biorefineries focusing on unavoidable wastes from processing [142], biorefinery approach for organic solid waste derived from agriculture, industry and urban communities [139], techno-economic and profitability analysis of food waste biorefineries [46], and sustainable approaches for conversion and reutilization of food wastes to valuable bioproducts [137]. In this vein, adopting suitable technical and economic strategies within a multi-disciplinary approach can support developing a sustainable biorefinery of food waste based on CBE principles and bridging the gap between waste remediation and product recovery [22].

4.4.7. Municipal bio-waste and food waste valorization via anaerobic digestion process

Valorization of municipal bio-based and food waste streams through applying anaerobic digestion, as a biological conversion technology, has constructed the focal point of this research cluster. This cluster included 90 articles with an average publication year of 2019.84. Anaerobic digestion as a recent subject of research had been also appeared as one of the main identified background research themes from the co-citation clustering analysis in the previous section. Apart from the aforementioned applications of anaerobic digestion in the previous section, anaerobic co-digestion of food waste and rendering industry streams for biogas production [143], anaerobic co-digestion of sewage sludge and wine vinasse [158], food waste anaerobic digestion for bio-energy production [147], identification of variables and factors that affect municipal bio-waste and food waste anaerobic digestion [146], and food waste anaerobic digestion impacts on biogas production and environmental impacts [145] are among recent research topics within this cluster.

Finally, Fig. 8 illustrates the general map of the results obtained from the co-citation and bibliographic coupling analyses, representing the main background research themes and emerging subject areas of research in biomass and organic waste literature in the CE context.

5. Implications for research: Opportunities and prospects

To follow both the waste hierarchy and the CE principles, reducing the waste from the source should be prioritized [159]. The biomass and organic waste source can be the food loss generated at any part of the food supply chain, food waste generated by the end consumers, or other biomass and organic wastes produced in the agricultural, horticultural, and industrial sectors. In any of these cases, proper strategies should be designed and adopted to inform and train waste generators about waste treatment methods, the ways to reduce waste, and the benefits and opportunities of converting waste to energy. In this regard, special attention should be devoted to (1) designing guidelines and rules for the agricultural and industrial sectors to encourage them to follow and promote CE principles in their activities to minimize waste and support them to feed their waste to a waste-to-energy process, (2) increasing the social awareness about the negative effects of waste generation and at the same time, informing them about the efficient food waste to energy conversion, (3) promoting the usage of biofuels and bio-fertilizers and

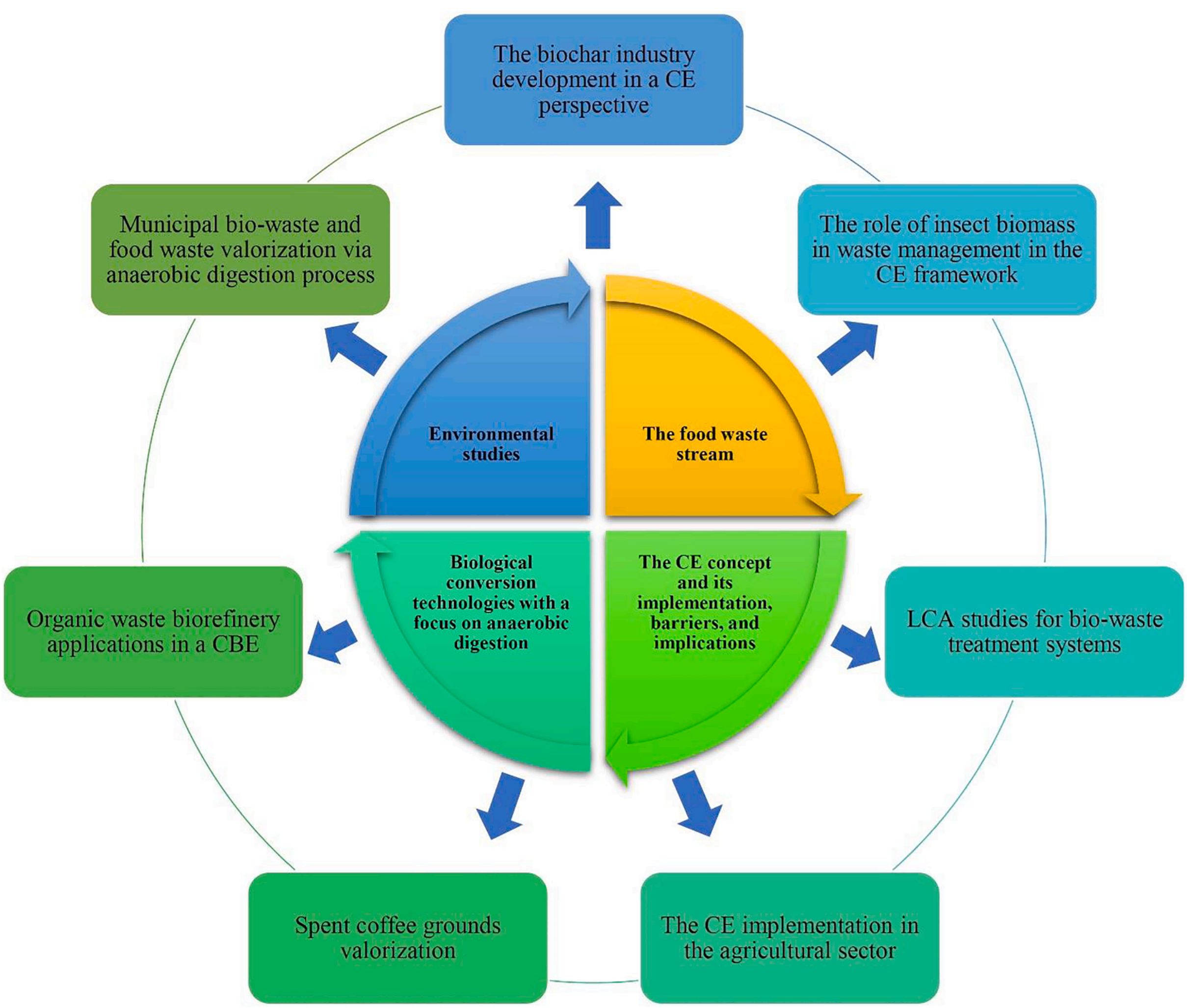


Fig. 8. The main background research themes and emerging subject areas of research in the research field of biomass and organic waste towards the CE.

increase the research and funding supports towards increasing the share of biofuels in the energy basket.

Besides the several applications of the biofuels derived from biomass and organic waste, the role of using biofuels in the decarbonization of transport systems has been highlighted in several research works [160]. On the other hand, the mobility restrictions during the COVID-19 pandemic shed light on the role of fossil-fuel-based transport systems on atmospheric pollution in urban areas [161]. Therefore, the current pandemic, with its effects on the economic, social, and environmental aspects of human lives [162,163], has provided an opportunity to promote the transition towards using greener energy sources, such as electricity and biofuels, in the transport sector. Using biofuels in the transport sector can be a potentially favorable solution, as it can lead to the elimination of waste and the replacement of fossil fuel at the same time, resulting in positive environmental outcomes [164]. Although biofuels have been used in the transport sector [165], more research, market analysis, and funding are required to commercialize alternative-fuel vehicles and encourage biofuels in transportation.

Using bio-wastes in the biorefineries to recover energy and material can be considered a clear step towards implementing the CE [8]. Environmental, economic, and social impacts of using waste in this process align with the three pillars of sustainability [19] and support sustainable development in rural areas [30]. However, a holistic view and systems thinking approach [166,167] to capture the interconnections among the variables and address the system complexity must be considered when assessing the sustainability and CE transition [168] in the activities linked with the waste-to-energy conversion practices. This systems thinking approach can also be coupled or supported by agent-based modeling [169] or data-driven approaches, such as machine learning [170], and artificial neural networks [171] to support decision-making towards process and product improvement and optimization. Data-driven technologies can also help establish and develop key performance indicators and baselines to better evaluate the performance at each stage of the waste-to-energy process [136]. Adopting a multi-disciplinary approach seems to be crucial in this regard to design proper and inclusive strategies.

6. Research limitations

The present research was conducted with limitations that can provide future directions for further development by scholars involved in this domain. First, the article clustering was performed based on two bibliometric methods, namely bibliographic coupling and co-citation analyses. Using other types of data clustering methods such as text mining-based methods and tools is recommended for more investigations on the same topic. Second, although we tried to cover all aspects of biomass and organic waste research in the CE context, our data was extracted only from the WoS database. Hence, considering other citation databases (e.g. Scopus) for extracting relevant data should be carried out in future research. Moreover, incorporating materials from secondary data, gray literature review, and snowballing techniques is highly encouraged to enrich the present research findings. And finally, defining separate research projects to comprehensively and systematically analyze and review each of the clusters identified in our research (i.e., the four co-citation clusters and the seven bibliographic coupling clusters) would be a valuable potential future avenue for researchers.

7. Conclusions

This research was the first attempt in the literature applying a systematic bibliometric analysis to render an inclusive image of the body of knowledge in biomass and organic waste research towards implementing a CE. To this end, two bibliometric methods, supported by co-citation and bibliographic coupling clustering techniques, were used to uncover the main research backgrounds and emergent subject areas of research, building the target literature.

The findings showed that the main founder research themes that have built the core background of the scientific production in biomass and organic waste applications in the CE had been mainly focused on (i) biological conversion technologies, (ii) conceptualizing the CE and its associated implementation strategies, (iii) environmental studies, and (iv) food waste management practices. On the other hand, seven emergent research areas that research communities have recently focused on were identified and discussed, including (1) the biochar industry development from a CE perspective, (2) the role of insect biorefinery in waste management in the CE framework, (3) LCA studies for bio-waste treatment systems, (4) the CE implementation in the agricultural sector, (5) spent coffee grounds valorization, (6) organic waste biorefinery applications in a CBE, and (7) municipal bio-waste and food waste valorization *via* anaerobic digestion.

The identified research themes through co-citation analysis with a backward-looking approach to the target literature and also uncovered subject areas through bibliographic coupling analysis with a forward-looking perspective provide a comprehensive portrait of biomass and organic waste research in the CBE context. In the end, potential directions for further research in the future were proposed to facilitate the CBE transition. The insights provided by the present bibliometric analysis are expected to help researchers and scholars to capture a general overview and landscape of the research conducted to date. Besides, it can be used as a guideline for policy-makers and industrial practitioners to advance recent developments within the field.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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